TITLE OF THE INVENTION
        DUPLEXER

BACKGROUND OF THE INVENTION

5   1. Field of the invention
        The present invention generally relates to
duplexers, and more particularly, to a duplexer having
surface acoustic wave filters formed on one substrate.
        2. Description of the Related Art
10   Antenna duplexers each having two surface
acoustic wave (SAW) filters are used for 800 MHz band
portable telephone devices and mobile communication
devices today. These SAW filters employed in antenna
duplexers are required to have high power durability to
15 perform stable operations and to achieve long lives.
Accordingly, the two filters of each duplexer have
normally been formed with ladder filters that have SAW
devices connected in a ladder-like fashion and exhibit
relatively high power durability.
20   As there has been an increasing demand for
smaller-sized portable telephone devices and mobile
communication devices, SAW filters that can be
relatively easily made smaller in size are preferred
for antenna duplexers used for 1.9 GHz band mobile
25 communication systems (such as Personal Communications
Services (PCS) for the North American market, for
example).
        To produce smaller-sized antenna duplexers is
expected whether it is for an 800 MHz band device or a
30 1.9 GHz band device. A smaller-sized antenna duplexer
can be produced by forming two SAW filters on one
substrate (as disclosed in Japanese Patent Application
No. 2002-237739, for example).
        However, two SAW filters formed on a small
35 substrate in an attempt to produce a smaller device
cause problems such as a decrease in the degree of
stop-band suppression and an increase in crosstalk

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between transmission signals and reception signals. These problems are conspicuous especially in 1.9 GHz band antenna duplexers than in 800 MHz band antenna duplexers, and for this reason, it has been difficult
5   to produce 1.9 GHz band antenna duplexers utilizing SAW filters.

So as to eliminate the problem of crosstalk between transmission signals and reception signals, two SAW filters are formed on two separate substrates to
10 produce an antenna duplexer.

However, the SAW filters should preferably be formed simultaneously on one substrate to produce an antenna duplexer. One of the reasons for this is to realize a small-sized antenna duplexer. The other
15 reasons are as follows. When two SAW filters are formed on two separate substrates, the center frequencies of the two SAW filters fluctuate with variations in the electrode film thickness and electrode finger width between process batches. As a
20 result, the gap between the center frequencies fluctuate by twice as much as the fluctuation of the center frequency of each SAW filter, causing large variations in the characteristics of antenna duplexers. When two SAW filters are formed simultaneously on one
25 substrate, on the other hand, the center frequencies of the two SAW filters are not affected by variations in the electrode film thickness and the electrode finger width. Accordingly, the gap between the two center frequencies does not vary greatly, and antenna
30 duplexers with desired filter characteristics can be obtained. As described above, the characteristics of each antenna duplexer are greatly affected by the gap between the center frequencies of the two SAW filters. It is therefore preferable to form two SAW filters
35 simultaneously on one substrate to achieve a higher yield.

As already mentioned, there are market demands

for higher-frequency antenna duplexers and smaller-sized antenna duplexers. If these demands are to be met, however, the crosstalk between transmission signals and reception signals increases. Therefore, it has been very difficult to achieve good filter characteristics.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide duplexers in which the above disadvantage is eliminated.

A more specific object of the present invention is to provide a duplexer that has two or more SAW filters on a single substrate and exhibits excellent filter characteristics with less crosstalk.

The above objects of the present invention are achieved by a duplexer comprising a ladder filter and a multimode filter that are formed on the same surface of a predetermined substrate, a first comb-like electrode of the ladder filter and a second comb-like electrode of the multimode filter having the same layer structure with the same film thickness, the first comb-like electrode and the second comb-like electrode being formed with single-layer films mainly containing aluminum, the relationship among the film thickness h of the first comb-like electrode and the second comb-like electrode, the center frequency f_1 of the frequency band of the ladder filter, and the center frequency f_2 of the frequency band of the multimode filter, being expressed as:

$$300 \leqq h \times f_1 \leqq 480$$
$$300 \leqq h \times f_2 \leqq 430.$$

The above objects of the present invention are also achieved by a duplexer comprising a ladder filter and a multimode filter that are formed on the same

surface of a piezoelectric substrate, a first comb-like electrode of the ladder filter and a second comb-like electrode of the multimode filter having the same layer structure with the same film thickness, the first comb-
5   like electrode and the second comb-like electrode being formed with single-layer films mainly containing aluminum, or single- or multi-layer films including n layers (n being an integer of 1 or greater), the n layers including a layer mainly containing a metal
10   other than aluminum, the relationship among the film thickness h_k of the kth layer (k being an integer of 1 or greater) of the first comb-like electrode and the second comb-like electrode, the specific gravity a_k of the metal of the kth layer with respect to aluminum,
15   the center frequency f_1 of the frequency band of the ladder filter, and the center frequency f_2 of the frequency band of the multimode filter, being expressed as:

$$300 \leqq f_1 \times \sum_{k=1}^{n} (\alpha_k \times h_k) \leqq 480$$

$$300 \leqq f_2 \times \sum_{k=1}^{n} (\alpha_k \times h_k) \leqq 430$$

20

BRIEF DESCRIPTION OF THE DRAWINGS
        Other objects, features and advantages of the present invention will become more apparent from the
25   following detailed description when read in conjunction with the accompanying drawings, in which:
        Fig. 1 is a block diagram illustrating the structure of a duplexer in accordance with a first embodiment of the present invention;
30   Fig. 2 is a top view of a ladder filter to be employed in the duplexer in accordance with the first embodiment;
        Fig. 3 is a top view of a multimode filter to be employed in the duplexer in accordance with the first

embodiment;

Fig. 4 is a graph showing the filter characteristics of the ladder filter shown in Fig. 2 and the filter characteristics of the multimode filter shown in Fig. 3;

Fig. 5 is a graph showing the results of simulations performed to examine the crosstalk from the transmission side to the reception side in the case of employing the multimode filter of Fig. 3 as the higher-frequency filter of the duplexer and in the case of employing the ladder filter of Fig. 2 as the higher-frequency filter of the duplexer.

Fig.6 is a graph showing transition bands in the transmission characteristic of the filter;

Fig.7 is a graph showing transition band variation with respect to the electrode film thickness of the ladder filter of Fig.2;

Fig.8 is a graph showing transition band variation with respect to the electrode film thickness of the multimode filter of Fig.3;

Fig. 9 is a graph showing the bandpass characteristics of the ladder filter of Fig. 2, with the value of the product of a thickness h and a center frequency f_1 being varied;

Fig. 10 is a block diagram illustrating the structure of a specific example of the duplexer in accordance with the first embodiment;

Fig. 11 is a graph showing the bandpass characteristics observed from the transmission side of the duplexer of Fig. 10 to the antenna and the bandpass characteristics observed from the antenna to the reception side;

Fig. 12 is a graph showing the crosstalk characteristics observed from the transmission side to the reception side of the duplexer shown in Fig. 10; and

Fig. 13 illustrates the parallel-connected multi-

stage DMS structure that is employed in the duplexer
shown in Fig. 10.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

5   The following is a description of embodiments of
the present invention, with reference to the
accompanying drawings.
(First Embodiment)
       A first embodiment of the present invention will
10   be first described in detail. Fig. 1 is a block
diagram illustrating the structure of a duplexer 1 in
accordance with this embodiment. The duplexer 1 has
surface acoustic wave (SAW) filters (a transmission
filter 11 and a reception filter 12) formed on a
15   substrate 10. So as to maintain excellent filter
characteristics in spite of a decrease in the size of
the duplexer and the use of high frequency, one of the
two filters 11 and 12 is formed by a ladder filter, and
the other is formed by a multimode filter. A phase
20   shifter 13 that is a matching circuit for matching
input impedances is provided on the line that connects
the SAW filters 11 and 12 to an antenna port 15 serving
as a common terminal of the SAW filters 11 and 12.
       Fig. 2 shows an example structure of a ladder
25   filter. As shown in Fig. 2, a ladder filter 110
includes comb-like electrodes (interdigital
transducers; hereinafter referred to as the IDTs) 111
connected in series, and IDTs 112 connected in parallel
to the IDTs 111. Here, resonators that include the
30   IDTs 111 connected in series are series-arm resonators,
and resonators that include the IDTs 112 connected in
parallel are parallel-arm resonators. The series-arm
resonators are arranged in series arms while the
parallel-arm resonators are arranged in parallel arms
35   in a ladder-like structure.
       On the other hand, a multimode filter exhibits a
great degree of stop-band suppression over a wider

frequency range than the ladder filter 110 does. Fig.
3 shows the structure of a multimode filter 120. As
shown in Fig. 3, the multimode filter 120 includes an
IDT 121 and two IDTs 122 arranged transversely, with a
5   reflection electrode 123 being provided on either end
of the arrangement. The IDT 121 is connected to the
input end, while the IDTs 122 are connected to the
output end. In the multimode filter 120, SAW is
excited, propagated and received. The structure shown
10   in Fig. 3 is the same as the structure of a double-mode
SAW (DMS) filter among several types of multimode
filters.
        As the ladder filter 110 having the above
structure is an electric circuit having the SAW
15   resonators as an impedance device formed by the IDTs
111 and 112, the degree of stop-band suppression of the
ladder filter 110 is not as great as that of the
multimode filter 120, due to adverse influence of stray
capacitance, or the like. Accordingly, one of the SAW
20   filters 11 and 12 of the duplexer 1 is embodied by the
multimode filter 120, so as to reduce crosstalk between
transmission signals and reception signals. This
structure will be described below, with reference to
Figs. 4 and 5.
25   Fig. 4 shows the filter characteristics of the
ladder filter 110 and the filter characteristics of the
multimode filter 120. As is apparent from Fig. 4, the
ladder filter 110 and the multimode filter 120 each
exhibits a very small insertion loss in a certain
30   frequency band. Accordingly, the ladder filter 110 and
the multimode filter 120 can be considered to have the
same filter characteristics in terms of pass band
insertion loss. As for the stop-band suppression on
the low frequency side (represented by the region
35   surrounded by the broken line in Fig. 4), the multimode
filter 120 excels the ladder filter 110 by
approximately 10 dB.

Fig. 5 shows the results of a simulation performed for examining the crosstalk from the transmission end to the reception end in a case where the high frequency filter (the reception filter 12) is the multimode filter 120, and a simulation performed for examining the crosstalk from the transmission end to the reception end in a case where the reception filter 12 is the ladder filter 110. In these simulations, the low frequency filter (the transmission filter 11) of the duplexer 1 is the ladder filter 110.

As is apparent from Fig. 5, the degree of suppression, especially the degree of suppression in the low frequency region (represented by the region surrounded by the broken line in Fig. 5), is improved with the multimode filter 120 as the reception filter 12, compared with the case of the ladder filter 110 as the reception filter 12. This is because the degree of stop-band suppression of the multimode filter 120 in that region is greater than that of the ladder filter 110 (also see Fig. 4). Judging from the results, it is obvious that more excellent characteristics in terms of crosstalk can be obtained with a structure having the multimode filter 120 as one of the two SAW filters of the duplexer 1.

The multimode filter 120, however, is poorer in power durability than the ladder filter 110. For this reason, if the two SAW filters 11 and 12 are formed with multimode filters 120, the power durability of the duplexer 1 greatly decreases. So as to maintain high power durability while improving the filter characteristics, it is preferable to employ the multimode filter 120 as one of the two SAW filters 11 and 12.

The ladder filter 110 and the multimode filter 120 (especially the IDTs 111, 112, 121, and 122) should preferably be made of the same metal with the same film thickness. This effectively simplifies the design and

production process, and also cancels automatically variations of the center frequencies of the two SAW filters 11 and 12 caused by variations of the electrode film thicknesses and the electrode finger widths of

5   process batches. Accordingly, simultaneous formation of the transmission filter 11 and the reception filter 12 brings about a correlation in the variations of the electrode film thicknesses and electrode finger widths that are caused during the production process. As a

10 result, a correlation appears also in the variations of the center frequencies between the two filters 11 and 12. As the difference between the center frequencies of the two SAW filters 11 and 12 that change in synchronization with each other does not change greatly,

15 desired filter characteristics can be easily obtained, and the yield of the duplexer 1 can be increased.

The IDTs 111, 112, 121, and 122 that form the two SAW filters 11 and 12 may be electrode films that are made of a metal mainly containing aluminum (Al), for

20 example. However, it is also possible to form a single-layer structure that mainly contains a metal other than aluminum (Al), or to form a multi-layer structure that includes such single layers. The metal other than aluminum (Al) may be titanium (Ti), copper

25 (Cu), gold (Au), molybdenum (Mo), tungsten (W), tantalum (Ta), chromium (Cr), platinum (Pt), ruthenium (Ru), or rhodium (Rh), for example.

The substrate 10 on which the two SAW filters 11 and 12 are formed may be a piezoelectric single-crystal

30 substrate of 42° Y-cut X-propagation lithium tantalate that is a rotated Y-cut plate (hereinafter referred to as a LT substrate), or a piezoelectric single-crystal substrate of 42° Y-cut X-propagation lithium niobate that is a rotated Y-cut plate (hereinafter referred to

35 as a LN substrate), for example. The substrate 10 may also be a piezoelectric substrate made of a piezoelectric material such as a certain kind of

crystal (hereinafter referred to as a piezoelectric substrate). With a LT substrate, the insertion loss is small.

In a case where the transmission filter 11 (the
5   ladder filter 110 in this embodiment) and the reception filter 12 (the multimode filter 120 in this embodiment) are formed on one substrate, i.e., in a case where two SAW filters of different types are formed on one substrate, it is difficult to obtain desired filter
10   characteristics for both SAW filters, because the optimum design parameters, especially the optimum electrode film thicknesses of the IDTs 111, 112, 121, and 122, are different between the multimode filter 120 and the ladder filter 110. Therefore, the inventors
15   have made an intensive study to determine the design conditions under which the ladder filer 110 and the multimode filter 120 exhibit excellent filter characteristics at the same time. The design conditions will be described below in detail.
20   First, variations in transition bands with respect to the electrode film thicknesses of the ladder filter 110 and the multimode filter 120 will be described. A transition band is a region on the boundary between a pass band and a stop band. In a
25   case where the ladder filter 110 has a pass band of -3.5 dB and higher, and a stop band of -42 dB and lower, the transition band is a frequency region from -42 dB to -3.5 dB. Likewise, in a case where the multimode filter 120 has a pass band of -4 dB and higher, and a
30   stop band of -50 dB and lower, the transition band is a frequency region from -50 dB to -4 dB.

Fig. 7 is a graph showing the dependence of transition bandwidth of the ladder filter 110 to be incorporated into a 1.9 GHz band duplexer for the PCS
35   (Personal Communications Services) on $h \times f_1$. In this ladder filter 110, the substrate 10 is the above described LT substrate, and the IDTs 111 and 112 are

formed by single-layer structures containing aluminum (Al) as the electrode material. In Fig. 7, the horizontal axis indicates the product $h \times f_1$ of the center frequency f_1 and the film thickness h

5 representing the thickness of the IDTs 111 and 112 of the ladder filter 110.

Fig. 8 is a graph showing the dependence of transition bandwidth of the multimode filter 120 to be incorporated into a 1.9 GHz band duplexer for the PCS

10 on $h \times f_2$. Like the ladder filter 110, the substrate 10 of this multimode filter 120 is the above described LT substrate, and the IDTs 121 and 122 are formed by single-layer structures containing aluminum (Al) as the electrode material. In Fig. 7, the horizontal axis

15 indicates the product $h \times f_2$ of the center frequency f_2 and the film thickness h representing the thickness of the IDTs 111 and 112 of the multimode filter 120.

The above ladder filter 110 is designed as a transmission filter (the transmission band: 1850 MHz to

20 1910 MHz) that conforms to the PCS standard, and the center frequency f_1 of the ladder filter 110 is 1880 MHz. The multimode filter 120 is designed as a reception filter (the reception band: 1930 MHz to 1990 MHz) that conforms to the PCS standard, and the center

25 frequency f_2 is 1960 MHz.

As the upper edge of the transmission band is 1910 MHz while the lower edge of the reception band is 1930 MHz, the gap between the transmission band and the reception band in the PCS is as narrow as 20 MHz. In

30 such a situation that the transmission band and the reception band is very close to each other, the filter characteristics of the transmission filter 11 and the reception filter 12 need to have very steep cutoff characteristics. In the above example, the

35 transmission filter 11 and the reception filter 12 need to have narrower transition band than 20 MHz. Judging from the filter characteristics of the ladder filter

110 shown in Fig. 7, the product $h \times f_1$ should be 480 or smaller so as to obtain narrower transition band than 20 MHz. Judging from the filter characteristics of the multimode filter 120 shown in Fig. 8, the

5   product $h \times f_2$ should be in the range of 300 to 430 so as to obtain narrower transition band than 20 MHz. If the electrode film thickness of the ladder filter 11 is too thin, however, ripples appear in the pass band, as shown in Fig. 9. Therefore, the lower limit of the

10   product $h \times f_1$ should preferably be 300 or greater. Fig. 9 is a graph showing the pass band characteristics variations of the ladder filter 110 that are observed when the product $h \times f_1$ is varied.

      For the above reasons, in a case where the IDTs

15   111 and 112 forming the ladder filter 110 and the IDTs 121 and 122 forming the multimode filter 120 are made of a metal with the same film thickness in the duplexer 1 having the ladder filter 110 and the multimode filter 120 formed on the same plane of a substrate, the design

20   conditions should be as follows:

$$300 \leqq h \times f_1 \leqq 480$$
$$300 \leqq h \times f_2 \leqq 430 \quad \ldots (1)$$

25   where: h represents the film thickness of each of the IDTs 111, 112, 121, and 122; f_1 represents the center frequency of the ladder filter 11; and f_2 represents the center frequency of the multimode filter 12. In this manner, the transition band of the

30   transmission filter 11 and the reception filter 12 can be 20 MHz or narrower, and the duplexer characteristics can be obtained which satisfies the PCS specifications, with suppressed crosstalk between transmission signals and reception signals can be reduced. Thus, improved

35   filter characteristics can be obtained.

      When the duplexer 1 is actually produced, it is more preferable to have a narrower transition band than

15 MHz, because there are variations in the electrode
film thicknesses and electrode finger widths of the
IDTs 111, 112, 121, and 122. So as to realize such a
transition band, the design conditions should be as
5 follows:

$$300 \le h \times f_1 \le 420$$
$$350 \le h \times f_2 \le 410 \qquad \dots (2)$$

10   Although the 1.9 GHz band duplexer 1 has been
described in the above description, the present
invention is not limited to the 1.9 GHz band, but may
also be applied to an 800 MHz band duplexer or a 2.0
GHz band duplexer. With such changes, the same effects
15 as described above can still be obtained. Accordingly,
the same graphs as those shown in Figs. 7 and 8 can be
obtained, regardless of change of the center
frequencies of the ladder filter and the multimode
filter.
20   Next, a duplexer 100 that has the above described
structure and satisfies the above described design
conditions will be described in detail.
       In this specific example, the above described
duplexer 1 is produced as a 1.9 GHz band antenna
25 duplexer to be used in the PCS. Fig. 10 illustrates
the structure of the duplexer 100.
       In this specific example, an LT substrate is
employed as the substrate 10. The transmission filter
11 formed on the substrate 10 is the ladder filter 110
30 of a four-stage structure having four series-arm
resonators, as shown in Fig. 2. The reception filter
12 formed on the substrate 10 is a parallel-connected
two-stage DMS filter that includes multimode filters
120a through 120f each having three IDTs 121 and 122
35 arranged in a row and also having reflectors arranged
at either end, as shown in Fig. 3. In this structure,
the multimode filters 120a through 120c are connected

to one side, and the multimode filters 120d through 120f are connected to the other side. Fig. 13 shows the connection relationship among the multimode filters 120a through 120f. Although Fig. 13 shows a single-phase input/output configuration, it is possible to employ a balanced input/output configuration. Further, the phase shifter 13 is provided between the input end of the reception filter 12 and the antenna port.

The IDTs 111, 112, 121, and 122 (see Figs. 2 and 3) that form the ladder filter 110 and the multimode filters 120a through 120f are single-layer structures that are produced simultaneously on the substrate 10. Each of the IDTs 111, 112, 121, and 122 has a single layer made of an electrode material mainly containing aluminum (Al), and the film thickness h of each of the IDTs 111, 112, 121, and 122 is 0.18 μm.

Accordingly, the value obtained by multiplying the film thickness h (= 1.8×10^{-7} m) by the center frequency f_1 (= 1.88×10^9 Hz) of each transmission filter 11 is approximately 338, and the value obtained by multiplying the film thickness h (= 1.8×10^{-7} m) by the center frequency f_2 (= 1.96×10^9 Hz) of the reception filter 11 is approximately 353, both of which satisfy the design conditions represented by the expressions (1). These values also satisfy the design conditions represented by the expression (2).

Fig. 11 shows the bandpass characteristics observed from the transmission side of the duplexer 100 to the antenna (i.e., the bandpass characteristics of the transmission filter 11) and the bandpass characteristics observed from the antenna to the reception side of the duplexer 100 (i.e., the bandpass characteristics of the reception filter 12). As is apparent from Fig. 11, the insertion loss is -3.5 dB or smaller in the transmission band, and is -4 dB or smaller in the reception band. The degree of suppression -50 dB or greater in the transmission band,

and is -45 dB or greater in the reception band. From these results, the duplexer 100 of this specific example proves to be useful in practical use.

Fig. 12 shows the crosstalk characteristics observed from the transmission side to the reception side of the duplexer 100. As is apparent from Fig. 12, crosstalk is restrained to -50 dB or greater in the transmission .band, and is restrained to -42 dB or greater in the reception band. With these results, the duplexer 100 of this specific example proves to have excellent characteristics and to be useful in practical use.

As the above described duplexer has electrodes made of the same electrode material with the same film thickness on the same substrate, the production process is simplified, and the production yield is increased.
(Second Embodiment)

A second embodiment of the present invention will now be described in detail. As in the first embodiment, the transmission filter 11 is the ladder filter 110 in this embodiment, and the reception filter 12 is the multimode filter 120 in this embodiment. In the first embodiment described above, each of the IDTs 111, 112, 121, and 122 of the transmission filter 11 and the reception filter 12 is a single-layer structure made of an electrode material mainly containing aluminum (Al).

Generally, it is preferable to form the IDTs 111 and 112 of the transmission filter 11 with electrode films having high power durability, because larger power is normally applied to the transmission filter 11 than to the reception filter 12. In view of this, the IDTs 111 and 112 are formed with electrode films having relatively high power durability in this embodiment.

More specifically, examples of electrode films having high power durability include metallic films each having a three-layer structure of aluminum-copper/copper/aluminum-copper (Al-Cu/Cu/Al-Cu), a

multi-layer structure in which a material mainly containing aluminum (Al) and titanium are laminated, a laminated structure of aluminum-magnesium (Al-Mg), and a laminated structure of aluminum-copper-magnesium (Al-Cu-Mg).

When the IDTs 111 and 112 of the transmission filter 11 (the ladder filter 110) are formed with the electrode films described above, it is effective to form the IDTs 121 and 122 of the reception filter 12 (the multimode filter 120) having the same layer structures through the same manufacturing procedures. By doing so, the power durability of the duplexer 1 is increased. Since electric power leaking from the transmission filter 11 flows into the reception filter 12, it is necessary for the reception filter 12 to have a certain degree of power durability. As the reception filter 12 is formed with electrode films having the same power durability as those of the transmission filter 11 as described above, the power durability of the reception filter 12 (the multimode filter 120) can be increased. Also, the IDTs 111, 112, 121, and 122 of the transmission filter 11 and the reception filter 12 that are formed as the same layer structures through the same procedures are advantageous not only in that the production process can be simplified, but also in that variations in the filter characteristics due to electrode thickness variations and electrode finger width variations can be restrained.

In a case where the IDTs 111, 112, 121, and 122 are made of an electrode material other than aluminum (Al), the electrode film thickness changes due to the difference in specific gravity between the employed electrode material and aluminum (Al). In this embodiment, however, the specific gravity of the electrode material with respect to aluminum is multiplied in a case where the IDTs 111, 112, 121, and 122 are formed with single- or multi-layer structures

including layers made of the electrode material other than aluminum (Al). By doing so, the specific gravity of the electrode material is converted to the electrode film thickness substantially equivalent to that of aluminum (Al), and the value of the electrode film thickness should satisfy the design conditions defined by the expressions (1). Here, the design conditions in accordance with this embodiment are as follows:

$$300 \leq f_1 \times \sum_{k=1}^{n} (\alpha_k \times h_k) \leq 480$$
$$300 \leq f_2 \times \sum_{k=1}^{n} (\alpha_k \times h_k) \leq 430 \quad \cdots \quad (3)$$

where: h_k represents the film thickness of each kth layer of the IDTs 111, 112, 121, and 122 (k being a natural number), and a_k represents the specific gravity of the electrode material of the kth layers with respect to aluminum (Al).

Like the first embodiment, when variations in the electrode film thicknesses and electrode finger widths of the IDTs 111, 112, 121, and 122 that form the duplexer 1 are taken into consideration, the transition band is considered to be 15 MHz rather than 20 MHz. Therefore, the design conditions are set as follows:

$$300 \leq f_1 \times \sum_{k=1}^{n} (\alpha_k \times h_k) \leq 420$$
$$350 \leq f_2 \times \sum_{k=1}^{n} (\alpha_k \times h_k) \leq 410 \quad \cdots \quad (4)$$

With these design conditions, the duplexer characteristics can be obtained which satisfies the PCS specifications with the suppressed crosstalk between transmission signals and reception signals in the same manner as in the first embodiment, even if the IDTs 111, 112, 121, and 122 of single- or multi-layer structures

are made of an electrode material other than aluminum (Al). Thus, a duplexer having excellent filter characteristics can be produced.

In a case where the IDTs 111, 112, 121, and 122 are formed with electrode films having multi-layer structures, however, the filter insertion loss increases due to the greater electric resistance than those formed with single-layers structures made of aluminum (Al). So as to counter such a problem, this embodiment employs a structure in which multimode filters 120 are connected in parallel in the same manner as in the structures of the first embodiment shown in Figs. 10 and 13. By doing so, the electric resistance of the reception filter 12 can be reduced, and the filter insertion loss is also reduced. The other aspects of this embodiment are the same as those of the first embodiment, and therefore, explanation of them is omitted herein.

Although a few preferred embodiments of the present invention have been shown and described, it would be appreciated by those skilled in the art that changes may be made in these embodiments without departing from the principles and spirit of the invention, the scope of which is defined in the claims and their equivalents.

The present application is based on Japanese Patent Application No. 2003-121871 filed on April 25, 2003, the entire disclosure of which is hereby incorporated by reference.